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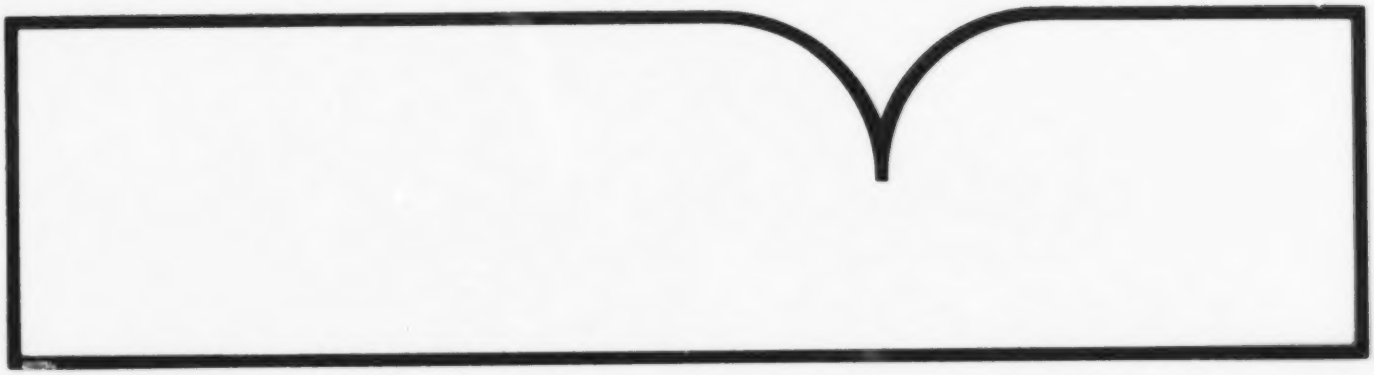

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16. ABSTRACT

The paper discusses an intensive investigation of radon source characterization, entry mechanisms, procedures for remediation diagnosis, and mitigation system performance evaluation being conducted in occupied New Jersey, USA, homes. The aim of the investigation is to examine the influence of environmental and building factors on radon entry into homes. One home serves as a control and remains in the original state during the experiment. Radon mitigation systems are installed in the other six homes. Indoor radon levels, indoor and outdoor temperatures, windspeed and direction, pressure differentials, and soil temperature and moisture are some of the parameters being monitored continuously. Soil air permeability, soil gas radon concentrations, ventilation rates, and radon progeny are also being measured periodically. The homes will be monitored for 12 months and various mitigation systems cycled on and off weekly. The relation of the various parameters to radon entry is discussed and implications for radon mitigation diagnostics are presented.

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Radon	Soils	Stationary Sources	07B	08G, 08M
Residential Buildings	Wind (Meteorology)	Indoor Air		04B
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AN INTENSIVE STUDY OF RADON AND REMEDIAL MEASURES IN NEW JERSEY HOMES: PRELIMINARY RESULTS

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Abstract

In order to examine the influence of environmental and building factors on radon entry into homes, an intensive investigation of radon source characterization, entry mechanisms, procedures for remediation diagnosis, and mitigation system performance evaluation is being conducted in occupied New Jersey, USA, homes. One home serves as a control and remains in the original state during the experiment. Radon mitigation systems are installed in the other six homes. Indoor radon levels, indoor and outdoor temperatures, windspeed and direction, pressure differentials, soil temperature and moisture are some of the parameters being monitored continuously. Periodic measurements of soil air permeability, soil gas radon concentrations, ventilation rates, and radon progeny are also being conducted. The homes will be monitored for a 12 month period and various mitigation systems cycled on and off on a weekly basis. The relation of the various parameters to radon entry is discussed and implications for radon mitigation diagnostics are presented.

Introduction

Recent discoveries of elevated indoor radon concentrations in residential buildings have stimulated an interest in understanding radon entry into homes and in techniques to reduce indoor radon concentrations. There have been relatively few intensive investigations of radon entry into buildings and of the building and environmental parameters that appear to influence this entry rate (4,5,9). These studies, along with other work (1,6,7) have revealed the significance of pressure-driven flow of radon-bearing soil gas as an important, if not dominant, source of indoor radon in buildings with elevated concentrations.

A number of mitigation techniques to reduce indoor radon concentrations have also been investigated (2,3,9). Passive techniques, such as sealing cracks and other penetrations in substructure walls or floors, and increased ventilation of crawl spaces, have been examined, although they appear to have limited effectiveness in many cases. Active techniques have also been explored, including sub-surface ventilation, venting of concrete block cavities, basement overpressurization, and the use of heat recovery ventilation. In most cases, however, the previous studies have focused on finding and deploying techniques that appear to reduce radon concentrations without exploring in any fundamental way the detailed physical principles that influence the efficacy of the mitigation system. In some cases, the effectiveness of the mitigation techniques has been observed to change with changes in weather or in operation of the house.

The objectives of this research project are to:

- extend our basic knowledge of the fundamentals of soil gas flow and radon entry into buildings and to improve our understanding of the relationships among radon entry rate and key variables such as the driving forces for radon entry, meteorology, soil characteristics, building structural types, ventilation rates, and location and area of

leakage pathways between the soil and building interior.

- develop a better basic understanding of why certain mitigation techniques work (or fail) and of the operational ranges of key parameters that affect the utility of these techniques, and
- provide a diagnostic analysis procedure that can be used in specifying appropriate and effective remedial measures, based on available information on the building structure and its soil environment.

Experimental

House selection

The seven homes for the study were selected from a group of 33 houses that had previously been chosen from a pool of 130 homes located in north-central New Jersey. The final choices were based on data gathered during a detailed site and house visit, in which both *in-situ* soil air permeabilities and soil-gas radon concentrations were measured. An intensive building survey was also conducted at each site, characterizing the building structure, space conditioning systems used, floor plans, *etc.* The seven homes selected all have basements, with basement walls constructed of unfilled concrete block. In some houses, additional substructural components are also present, such as adjoining crawl spaces or slab-on-grade construction. Construction methods also differ in detail from house-to-house. The sites and the building substructure and components were chosen to be representative of homes typically found in that area and with the intention of providing a range of soil air permeabilities.

Instrumentation

Three types of measurements are being conducted, 1) continuous data acquisition using a data logger in each home, with periodic downloading to portable computer disks for data transfer to a laboratory-based computing system (indoor radon concentrations in the basement and first floor, radon in soil gas, indoor and outdoor temperatures, windspeed and direction, pressure differentials across the building shell at various locations, soil moisture and temperature, and barometric pressure and precipitation at one central site), 2) periodic measurements (*in situ* soil air permeability, building ventilation rate, indoor water vapor, snow depth, grab samples of soil gas at various locations for radon analysis, parameters associated with mitigation system operation, and occupant activities, including building or mechanical system operations), and 3) single characterization measurements (building effective leakage area and pressure field mapping, and laboratory analyses of soil grain size distributions, soil radium content and emanation ratio.)

Measurement procedures and timing

Field measurements will extend for a full year in order to evaluate seasonal effects on both the baseline measurements and the operation of the mitigation systems. Instrumentation deployment took place during September in order to obtain baseline data before the onset of major seasonal changes. During the two month baseline period, both continuous and periodic measurements of various parameters were taken. In addition premitigation diagnostic measurement procedures were developed and applied in order to identify radon entry locations in each of the seven structures (8). These results were also used to assist in designing and deploying mitigation systems in six of the houses; the seventh house remains in its original state as a control. Five of the six houses have had a second mitigation system installed as well, in order to evaluate directly the two alternative systems.

Continuous measurements will continue throughout the study, with the mitigation systems alternately cycled on and off for one week periods, interspersed with a week of no active radon mitigation to reestablish baseline conditions. In addition, periodic sampling including evaluations of mitigation system performance and laboratory analyses will continue.

Discussion of Preliminary Results

Continuous data

Approximately 30 channels of data have been collected continuously at each house, with data recorded every 30 min. A sampling of these data from one house is illustrated in Figure 1. The data were acquired during a two week period in November 1986, before mitigation systems were installed. The first three curves in the figure appear to behave in a similar manner. The basement radon concentration varies by more than a factor of five within a 2 day period, and exhibits a diurnal variation extending for most of the two week period. These same patterns have been observed in some, but not all, of the houses in this study for much of the measurement period. The average differential pressure between the basement and outside the building shell at ground level has been plotted so that an increasing negative pressure difference is shown as an upward change in the curve. These data exhibit variations similar to the radon concentration data, as does the difference between the indoor temperature at the first floor and the outside temperature. The indoor-outdoor temperature difference is one of the driving forces (the thermal stack effect) responsible for the pressure difference across the building shell. Wind loading on the building shell also contributes to the pressure difference, and might help explain some of the detailed differences in these curves. The pressure difference, in turn, is responsible for pressure-driven flow of soil gas into the building. These data appear to confirm, at a general level, the importance of convective soil gas flow into buildings as a source of indoor radon. Data from four of the other houses appear to follow a similar pattern, showing a correspondence between the temperature and pressure differentials and the resulting basement radon concentrations. In two of the houses, the preliminary data analysis indicates that peaks in the basement radon concentration lag the apparently corresponding increase in differential pressure, in some cases by a few hours.

Also shown in Fig. 1 are radon concentrations in the soil gas, monitored continuously via a probe inserted through the basement floor, soil temperatures measured at two soil depths at a location approximately 1 m from the house, and the barometric pressure data for the same period. Neither the barometric pressure nor the soil-gas radon levels appear to be associated with observed fluctuations in basement radon concentrations. As can be seen, the soil temperatures show a slight downward trend during this two week period, which was a time of seasonal change in the weather.

Other data

Soil gas radon concentrations range from ca. 2×10^4 to 3.3×10^6 Bq m^{-3} at one house, and similar site-to-site variations have been seen. Soil air permeability measurements have also been observed to range over several orders of magnitude, from $\sim 10^{-12}$, the current detection limit of the field instrumentation, to 10^{-8} m^2 both within a specific house site and among the seven house sites. Average basement radon concentrations span values from $\sim$ 850 to over 8000 Bq m^{-3}, and the ratios of first floor to basement radon concentrations range from about 0.25 to 0.75.

Remedial measures

The mitigation systems installed in the study homes are generally of three types, subslab ventilation systems that can operate in either an underpressure or overpressure mode, basement ventilation via an air-to-air heat exchanger, and basement pressurization. In each case, installation has been followed by a period of system optimization and evaluation of each component. Extensive measurements of the reverse pressure field established by subslab depressurization are being conducted using an array of small holes bored through the basement walls and slab. Other mitigation system diagnostics include air flow rates and radon concentrations in the exhaust stream of the subslab ventilation system. Preliminary results show reductions in basement concentrations to below 150 Bq m^{-3} from some of the houses where subslab depressurization systems are being used. Several of the systems have

not yet been fully optimized so final performance data are not available. In addition to evaluating possible seasonal effects on mitigation system operation, the systems will be challenged using a blower door to mechanically depressurize the house beyond the pressure range achieved naturally.

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Fig. 1. Continuous data on radon concentrations and environmental paramters observed in one house during a two week period in November 1986. The data interval is every 30 min. The data values alternate between the right and left axes beginning with the top-most curve referring to the right axis. Note that in the cases of the soil-gas radon concentration and barometric pressure the axes labels do not begin with zero, and that for the differential pressure, the axis labels are in terms of increasing negative pressure.